The Musée du Cinquantenaire in Brussels is not a science museum, but a museum of art and civilisation (Musées Royaux d'Art et d'Histoire is the proper name). Yet there is a whole wing dedicated to technological innovation: in everything from glass manufacture, to household objects, to clocks. Timekeeping is so intrinsic to technological and scientific progress. If you visit Greenwich observatory you will notice that almost the whole museum is dedicated to chronometers. Among them is Harrison's *marine chronometer*, still ticking after two and a half centuries (with a few intervals for cleaning and maintenance of course).

Why build a whole museum around a clock? Here I must refer you to Dava Sobel's *Longitude*. She called it "the story of a lone genius". The book has been praised to high heaven (even though it contains some errors of historical interpretation). Now the myth of the lone genius is one which we have discussed. How can we have a lone genius if scientific and technological innovation is a cumulative process? Doesn't this imply, by definition, that geniuses are merely part of a network spanning time, space and disciplines?

I want to talk about that interconnectedness.

Let us start with the problem of longitude. Latitude and longitude are simply coordinates on the surface of a sphere. We have an origin or reference point (the prime meridian and north pole), and a regularly-spaced grid. The Earth is in fact not perfectly spherical, but it makes no difference to the geometrical concept. The idea of coordinate geometry is extremely portable and adaptable.

Measuring the latitude was simple. It was simply a question of measuring the angle between the sun and the horizon. The problem was solved fairly early on. Astrolabes were not uncommon, even in the early middle ages.

Why would we want to measure our longitude accurately?

If we know our exact starting position, and if we know our exact speed and route, we can find our position anywhere on the globe. The trouble is to measure the exact speed and route.

When navigating close to the coast, as was the norm in the Mediterranean, you can use a combination of dead reckoning and coastal landmarks to keep track of your position. Your galley would sail (and row) down the Adriatic from Venice, and you would be taking bearings off known landmarks – the bell-tower of St Mark's in Venice, or features on the Dalmatian coast. But in oceanic navigation, out of sight of land, with winds and currents changing speed and direction, dead reckoning becomes very inaccurate.

By the 17^{th} century, ships were criss-crossing the oceans on a regular basis. Accurate navigation was needed when new lands were discovered and claimed. Moreover, maritime commerce and naval warfare was a lucrative but risky business. Investment banking and insurance (financial innovation…) systems were developed to fund voyages and provide insurance cover for the shipping industry (think of Lloyd's of London, founded in 1688).

Financial markets fear uncertainty. States fear territorial squabbles. Accurate navigation became essential. Hence the need to measure longitude.

Two solutions are possible.

Method 1: We can either use a universal signal, visible from any point on Earth, whose time of manifestation at the prime meridian is known. This must therefore be an astronomical phenomenon. This method is valid for any planet orbiting the Sun or another planet, regardless of whether the planet revolves on its own axis or not. If it does not, the calculation is complicated, but doable.

Method 2: Or we can carry with us a time-keeping apparatus which keeps the time of the prime meridian. This method is only valid if the planet revolves on its own axis.

Now the Earth revolves on its own axis once every 24 hours. It is the result of the initial angular momentum which it conserved. Some planets in the solar System have gradually lost that angular momentum because of tidal gravitational fields, so their period of revolution becomes equal to period of their orbit. Our own Moon is an example. We can only see one side of the Moon. Callisto, one of Jupiter's moons, is another example. More on Callisto later.

The Earth turns on its axis. That axis passes through the Earth's two poles. If you were to look up at the night sky at the North Pole, you would see all the constellations revolving around a central point close to Polaris, the pole star.

Method 2 is mathematically simpler. It does not depend on accurate astronomical observations to find longitude. Sobel's book tells the story of John Harrison who set out to solve the problem in a direct way: by producing a reliable clock.

The story of Harrison's chronometer is a wonderful example of technological innovation. The accuracy of any mechanical clock depends on a very basic scientific principle: conservation of energy. The clock contains moving parts, which will dissipate energy because of friction. The clock will then slow down. Harrison knew this, and his efforts were focussed on reducing friction. He also knew that a pendulum clock, which depends on the regular motion of the pendulum, was useless on a pitching and rolling ship. A spring-driven clock was the solution, since a wound-up spring delivers energy regardless of its orientation.

Harrison received several payments from 1734 to 1765 out of the Longitude Prize, which had been set up in 1714. The best innovators need financial backing, and several governments, seeking a technological edge over competing powers, provided financial incentives for the solution of the longitude problem.

Britain had its Royal Society and its Board of Longitude. France had its Academy of Science (Académie des Sciences) founded in 1666. At the instigation of Colbert, Louis XIV, it offered funding to scientists and inventors who could solve the longitude problem.

Among others, it funded the astronomer Richer's expedition to Cayenne in 1672 to measure the variation in the period of a pendulum. Cayenne, in present-day French Guyana, is closer to the equator than Paris, and the gravitational pull over there is smaller. The difference is tiny, but if you're launching a rocket into space every extra gram of lift counts, which is why the French space agency chose Kourou in French Guyana as its spaceport.

Back to longitude. On 24 April 1634, Louis XIII promulgated an ordinance fixing the prime meridian at El Hierro, or Isla del Meridiano, one of the Canary Islands, 20 degrees west of Paris. Why? Because this was the westernmost point in the old Known World – the edge of the world, as it were. Beyond lay the New World. All longitudes in Europe would therefore have positive values. All nice and tidy.

One item on your list of "suggested reading" is Umberto Eco's *The Island of the Day Before.* Originally published in Italian as *L'Isola del Giorno Prima*, it tells the story of Roberto della Griva, a northern Italian nobleman and adventurer who is marooned in 1643 on a ship anchored within sight of an island. Between the ship and the island runs the international date line. Hence the title of the book.

Roberto had been aboard an English ship on a mission to find the Solomon Islands, which were believed (says Eco) to mark the prime meridian. The islands would therefore provide an accurate measurement of longitude.

The book talks about scientific paradigms - longitude, physics, pendulums, and astronomy - against a background of personal and political turbulence – the Thirty Years' War, human relationships and needs, and human belief in god and heaven.

The front cover of the Mariner books edition of *The Island of the Day Before* shows a picture of The Heavens. It is fresco by Italian mannerist painter Rafaellino da Reggio at Palazzo Farnese, on the ceiling of the Sala della Cosmografia (the Hall of Cosmography). It shows the the constellations. Gods, nymphs and heroes come to life in vivid detail on the celestial sphere.

The constellations are one of the earliest cultural memes. They are a scientific paradigm – a model of a physical observation. They were hugely important in Hellenic civilisation, which itself adopted constellations that had been identified by Babylonian civilisation. By the time of the Roman Empire, the meme had gone viral. So it was preserved intact when the Western Roman Empire collapsed, passed on to Arabo-Muslim and Byzantine civilisation, then re-injected into Latin Christian civilisation in the middle ages.

Thus, when Rafaellino da Reggio painted his ceiling in the 16th century, he could be absolutely sure that this audience would understand. Culturally, he was on home turf.

And the meme has survived into our own times. In 1993, at the Théatre de la Monnaie in Brussels, within walking distance of the Musée du Cinquantenaire, conductor René Jacobs and *Concerto Vocale* performed the opera *La Calisto* (Calisto). Director Herbert Wernicke chose de Reggio's painting as his backdrop.

La Calisto, by Francesco cavalli, premiered on 28th November 1651 at the Teatro Sant'Appolinare in Venice. The plot concerns Jove's love for Calisto, who is a follower of Diana, and the former's attempt to seduce Calisto while disguised as the latter, abetted by Mercury. It starts out with stral chaos. A meteor has crashed to Earth. Crops fail and the people are covered in ash clouds. This is not doomsday but the opening scenario of the opera. The story is based on the Greek myth of the little nymph Calisto who turns into a big constellation, Ursa Major.

Cavalli's characters play out the story inside a box representing the heavens and the Earth, with da Reggio's *Constellations* showing the heavens.

In the *final scene*, night falls on Arcadia. Jupiter and other celestial spirits gather in Empyrean to celebrate Calisto's ascension into the heavens, she turns into Ursa Major, the Great Bear (06:22 in the video clip).

Wernicke chose to project a coordinate grid onto the painting at this point. There is now order in the cosmos. Ursa Major is significant because the North Star (Polaris), the current northern pole star on Earth, can be found using it. Polaris is part of the "Little Dipper", Ursa Minor.

When Polaris is directly overhead, the spot beneath your feet is where all the lines of longitude meet.